

PLASMA EXPERIMENT FOR PLANETARY EXPLORATION (PEPE)

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Abstract

The Plasma Experiment for Planetary Environments (PEPE) is one of the new instrument technologies being demonstrated with the New Millennium Deep Space One mission. PEPE will serve three purposes, (1) the characterization of the environment induced by the Solar Electric Propulsion (SEP) system while validating the feasibility of flying high performance plasma instrumentation on future SEP missions, (2) to carry out state-of-the-art plasma measurements in support of the scientific investigation of an asteroid and comet flyby, and (3) to validate several new plasma sensor technologies needed for future space physics and planetary missions. PEPE's measurement capabilities approach those of the Cassini Plasma Spectrometer (CAPS) instrument, but with much lower resource requirements, at a lower cost and delivered on a much faster time table. PEPE will provide three dimensional mass-resolved plasma distributions up to 30 keV over 2.8π ster on a time frame of 64 seconds. PEPE simultaneously measures both ions and electrons and provides energy per charge analysis and time-of-flight measurements to yield high resolution mass analysis. Details of the PEPE design are presented as well as an overview of both the technology and scientifically driven measurement objectives. The potential future applications of PEPE technology are also discussed.

INTRODUCTION

The Deep Space-1 (DS-1) mission is the first in NASA's New Millennium Program. The primary focus of the program is to demonstrate and validate new technologies for use in future space exploration. The Plasma Experiment for Planetary Exploration (PEPE) is included in the DS-1 payload to participate in the validation of the Solar Electric Propulsion (SEP) technology and to support the investigation of DS-1's primary science targets, a comet and an asteroid as well as demonstrating new space plasma observation technologies.

The PEPE instrument invokes new technologies combined with a novel design of electrostatic optics to providing state-of-the-art plasma measurements for both ions and electrons. The DS-1 mission will serve to validate the new technologies of PEPE, the feasibility of flying high performance plasma instrumentation on spacecraft equipped with SEP, the characterization of spacecraft effects associated with SEP, and will provide fundamental measurements of the physical processes in the solar wind and the interaction of the solar wind with comets and asteroids.

NEW TECHNOLOGIES

The PEPE design is, in part, an evolution of the Cassini Plasma Spectrometer (CAPS) (Young et al. 1996) with modifications focused on reducing resource requirements while maintaining state-of-the-art high performance. PEPE provides nearly the performance of the CAPS instrument (e.g. PEPE's energy range is 3 CV to 30 keV, that of CAPS is 1 CV to 50 keV) for approximately 20% of the mass, 25% of the power and 25% of the cost. The primary new technologies are:

- (1) a miniaturized linear electric field high resolution time-of-flight mass spectrometer approximately ten times smaller in volume than CAPS,
- (2) a confocal ion/electron electrostatic optics design providing plasma measurements with wide energy and angle coverage at high sensitivity,
- (3) low resource high speed (> 1 GHz) electronics for particle detection and time-of-flight mass spectrometry,
- (4) low resource high voltage power supplies for detectors and electrostatic optics requiring 75% less mass than CAPS power supplies,

- (5) an embedded sensor/electronics packaging technique using co-located optics and electronics,
- (6) low resource high performance central processing unit (CPU) tailored to a time-of-flight sensor and requiring less than 5% of the CAPS CPU resources.

The combination of these new technologies with the novel optical design provides PEPPI with the ability to obtain rapid energy per charge, mass per charge, and velocity distributions of ion species and electrons simultaneously. Most data is expected to be compressed at approximately 150:1 prior to transmission. Nominal operations will require telemetry rates of 50 bps. Occasional high time resolution observations near the comet and asteroid targets will require short periods of 1 kbps data rates.

INSTRUMENT DESIGN

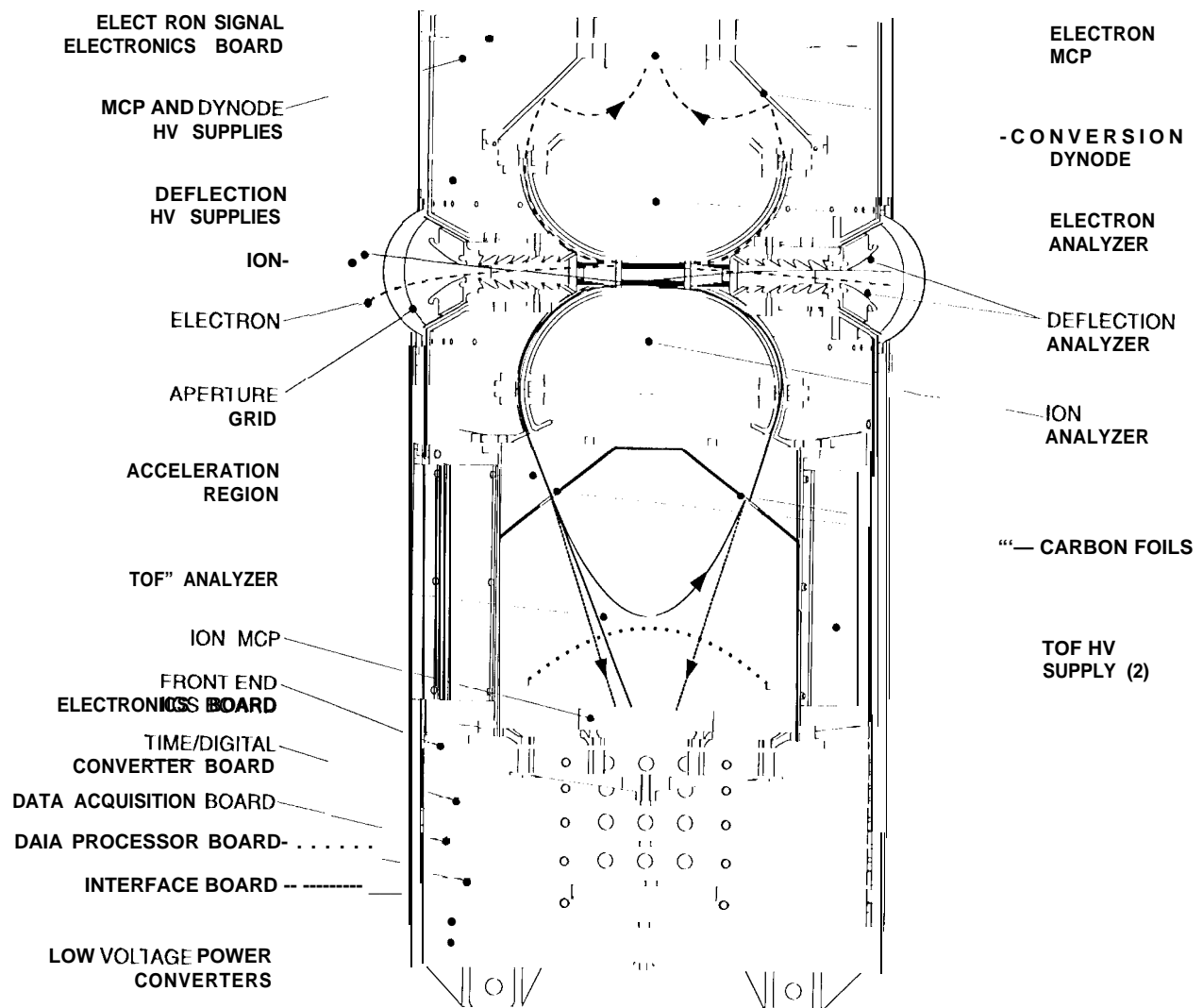


FIGURE 1. PEPPI Instrument Design.

Conceptual Design

PEPPI will measure electrons and ions simultaneously at a given energy and angle. This is accomplished using the compact cylindrically symmetric optical design shown in Figure 1. Ions and electrons enter PEPPI and are directed

to the appropriate energy analyzer by electrostatic deflection using two exponentially shaped deflection plates charged to opposite polarity. The particles are then collimated and deflected into an ion or electron toroidal tophat electrostatic analyzer (Young et al. 1988). The incoming ions are directed into a -15 kV field which accelerates them into ultra thin carbon foils which in turn emit electrons starting the time-of-flight timing circuitry. Ions with energies less than 15 kV "bounce" in the linear electric field providing the basis for high resolution time-of-flight velocity analysis (McComas et al. 1990). The incoming electrons are directed by the electrostatic analyzer onto a conversion dynode stimulating secondary electron emission which is detected by the electron microchannel plate.

Instrument Performance

PIEPI is capable of measuring ions from 3 eV to 30 keV and electrons from 10 eV to 10 keV with energy resolution of 0.05. Complete coverage of the energy distribution is accomplished by voltage stepping. A complete scan requires 2048 steps of the angle deflection and energy deflection optics; however, the number of steps can be defined based on mode choice. Instantaneous high resolution mass analysis is provided for the range of 1 to 135 amu with a M/AM of 50 (FWHM). Elevation angle is sampled in 5 degree steps for a full range of 90 degrees. Azimuthal angle is obtained instantaneously with 45 degree resolution for the full 360 degree range (minus spacecraft obstructions) with one 45 degree sector further subdivided into 5 degree flat resolution sectors. The elevation angle and energy scan modes are defined such that elevation angle is stepped through the full 90 degree range in 1 second. Sampling each energy step at 30 ms, PIEPI obtains a full three dimensional scan in about 1 minute. A summary of the PIEPI performance is provided in Table 1,

TABLE 1: PIEPI Instrument Performance Data (Preliminary)

Energy	range resolution scan	ions, 3 eV to 30,000 eV electrons, 10 eV to 10,000 eV ΔE/E = 0.05 stepped, mode dependent
Elevation Angle	range resolution scan	+/- 45 degrees 5 degree stepped
Azimuthal Angle	range resolution scan	360 degrees 45 degrees none (instantaneous)
Mass Composition	range resolution scan	1 to 135 amu M/AM = 50 (FWHM) none (instantaneous)
Temporal Composition	single sample elevation scan full 3-D	30 ms 1 s 64 s
Sensitivity	ions electrons	$10^{-3} \text{ cm}^2 \text{ sr eV/eV}$ no composition $10^{-4} \text{ cm}^2 \text{ sr eV/eV}$ with composition $10^{-3} \text{ cm}^2 \text{ sr eV/eV}$

OBJECTIVES AND OPERATIONS

The primary objectives of the PIEPI instrument are a combination of technology validation and scientific investigation. The technology validation involves understanding the effects of SEP on the spacecraft as well as determining whether conditions associated with SEP compromise the performance or health of plasma sensors. In addition to the technology validation associated with SEP, the new technology incorporated in the PIEPI design also requires validation, although, this will in part be tested in pre-launch calibration. The science objectives of PIEPI parallel those of the DSS-I mission and are focused on solar wind, cometary and asteroid science.

PIEPI operations are comprised of two distinct phases corresponding to the two objectives described above. Validation of the SEP technology requires PIEPI to provide measurements of the effects on the space plasma environment associated with the propulsion system. During periods when the SEP is active, high resolution mass analysis will provide detailed characterization of the products of the propulsion system such as Xe^+ and Mo^+ . Effects on the solar wind plasma and spacecraft charging will be studied in detail along with establishing health and safety issues regarding the use of plasma sensors with SEP. A fundamental goal of PIEPI is to test the ability to

obtain reliable information on physical processes in magnetospheric and solar wind plasmas on future S13P equipped spacecraft.

The primary science objectives of DS-1 will be obtained during periods when the S13P is off. During cruise P13P1 will study the solar wind ion and electron velocity distributions, ion composition and suprathermal distributions along with detailed investigation of solar wind boundaries such as high speed streams, shocks, and coronal mass ejections. At the comet encounter P13P1 will search for pick-up ions, coma plasmas related to outgassing and the interaction of the comet with the solar wind. P13P1 is particularly adept at measuring ion composition including the water group ions important in cometary physics. During the asteroid flyby, P13P1 will search for any asteroid atmosphere resulting from surface outgassing and photo-ionization. Characterization of the processes surrounding the asteroid will be used to investigate whether asteroids are magnetized as suggested by the Galileo magnetometer team during the close flyby of the Gaspra asteroid.

FUTURE APPLICATIONS

The P13P1 design offers high sensitivity, high resolution measurements of plasma composition and velocity (distributions) at a fraction of the resources required by traditional plasma instrumentation. A number of the new technologies being developed for P13P1 are important in demonstrating the ability to obtain high sensitivity measurements without sacrificing high mass resolution over a wide range of mass and energy. The applications of P13P1 technology are particularly well suited for performing Earth orbiting and deep space missions at a fraction of the costs of previous designs. P13P1 is well suited to **explore solar** wind and magnetospheric science objectives while maintaining the versatility of offering the ion composition measurements important in exploring the terrestrial planets and the satellites of the outer planets. Intriguing results from recent flybys of the Jovian moons Io and Ganymede are demonstrating the importance of studying the interactions of satellites with magnetospheres in understanding the past and present physics of our solar system. P13P1 based designs are currently part of two Discovery mission proposals to study Mercury and the Martian moon Phobos.

Acknowledgments

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